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Design and Optimization of 150 m Higher Wind Monitoring Tower (Indian Condition)

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ABSTRACT

In order to locate a 150m wind monitoring tower to measure the wind characteristics, we investigated the site near Paradip, Odisha (India) to locate wind tower and collected some wind data to incorporate into the design of tubular steel tower. This paper seeks to understand the design of tubular steel tower and its performance parameter up to 150m height, also it provides the stability analysis such as static, buckling and vibration using computer optimized approach. The main objective of this paper is to explore more wind potential by measuring the wind data at 150m height and to locate a safe and economic tower at this location, it will produce more power output and would boost the economy of India in a very rapid manner which is the current major issue of our society.

Keywords: Buckling, Onshore tower, Static, Vibration.

1. INTRODUCTION

Due to increasingly demand of power in India wind technology has always been the key issue to supply more power while maintaining the minimum investment in energy sector. For any wind turbine installation near about 30% cost is associated with the tower. So, the effective way to reduce the total cost of wind turbine is to just reduce the total tower cost. Since, for any wind turbine tower power is a cubic function of a wind velocity, so to increase the power the most effective way is to design the high rise wind tower. As per the International Electro technical Commission (2007), if we increase turbine elevation from 80 m to 100 m, it will give 4.6% larger wind speed and a 14% increased power output. Similarly, an increase from 80 m to 120 m would result in an 8.5% greater wind speed and a 28%increase in power production. [3] Brughuis et. al, 2004 had suggested the criteria to install few more higher tower compare to larger small tower . As per [4] LaNier et. al (2005), the total cost for a 3.0 MW, (120 m) tower is $3,445,150. Out of that $551,415 is associated with the tower materials and $195,160 is associated with tower transportation, which is near about 21.7% of the total cost of each wind turbine.

2. LITERATURE REVIEW

Collection of data from the portal of paradip port located at (20°15′55.44″N 86°40′34.62″e) in Jagatsinghpur district of Odisha India. [9] It is situated at confluence of the Mahanadi river and the Bay of Bengal.IS:875 [8] code is used to calculate design wind speed upto 150m height, it can be further extended to more than 150m height also.[1] A. Quilligan et.al has worked on the Fragility analysis of steel and concrete wind turbine towers.[2] Burton et. al had given the local buckling criteria. [7] Ugural et.al given the failure theory in ductile material. [6] P.E. Uysa et.al also worked on the cost minimizing approach of steel shell tower.[5] Maalawi KY et.al had given stiffness maximizing approach.[7] Ugural and Fenster et.al had the stress tensor matrix approach at the critical section of the tower.

3. ASSUMPTIONS

1.0 Tower is assumed as a cantilever beam with linear varying cross-section and thickness, concentrated as a point mass (Weight of tower, instrument, 20% margin) acting at the top end.
2.0 Material is to be following Hook's law of elasticity.
3.0 Euler-Bernoulli theory is used in buckling analysis.
4.0 Neglecting the effect of drag force caused by air flow.

4. METHODOLOGY

The allowable local buckling stress method involves-
1) Calculating the elastic critical buckling stress of a cylindrical steel tube, which has modulus of elasticity Es, wall thickness t_w, and mean radius r_m, in axial compression.
2) Calculating critical stress reduction coefficients for bending and axial Loading.
3) Plugging these values along with the material's yield strength f_y to obtain the allowable local buckling stress. The maximum principal stress in the structure should not exceed this allowable local buckling stress value in order to avoid local buckling.
Burton et.al [2] given the local buckling criteria,

$$\sigma^{bucling} = \left\{ fy \left[1 - 0.4123 \left(\frac{fy}{\alpha^b . \sigma^{cr}} \right)^{0.6} \right] \right\} , \alpha^b . \sigma^{cr} > \frac{fy}{2} \quad \text{Eq.1}$$

$$0.75\alpha^b . \sigma^{cr} , \alpha^b . \sigma^{cr} \leq \frac{fy}{2} \quad \text{Eq.2}$$

$$\sigma^{critical\ \ elastic} = 0.605\ Es\ \frac{tw}{rm} \quad \text{Eq.3}$$

$$\alpha^b = 0.1887 + 0.8113\alpha^o \quad \text{Eq.4}$$

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$$\alpha^{o} = \begin{pmatrix} \frac{0.83}{\sqrt{1+0.01\frac{rm}{tw}}}, & \frac{rm}{tw} < 212 \\ \frac{0.70}{\sqrt{0.1+0.01\frac{rm}{tw}}}, & \frac{rm}{tw} \geq 212 \end{pmatrix} \quad \text{Eq.5}$$

The maximum distortion energy theory states that yielding will occur when the distortion energy per unit volume is equal to that associated with yielding in a simple tension test. This theory is commonly used in engineering design because of its proven track record for predicting failure in ductile Materials. Principal stresses σ^1, σ^2 and σ^3 are obtained at the critical points in the tower. In practice, an appropriate factor of safety fs, is applied to reduce the material's yield stress σ_{yp}.

Ugural et.al [7] given the maximum distortion energy theory for ductile material,

$$(\sigma^1-\sigma^2)^2+(\sigma^2-\sigma^3)^2+(\sigma^3-\sigma^1)^2 = 2\left(\frac{\sigma^{yp}}{Fs}\right)^2 \quad \text{Eq.6}$$

Total weight assumed on the tower,
=Weight of the tower +weight of the instrument+20%with the weight of the instrument,
As per IS: 875,[8]

$$Vz = V_b * k1 * k2 * k3 * k4, \quad \text{Eq.7}$$

The design wind pressure P_d can be obtained as,

$$P_d = 0.6*K_d*K_a*K_c*V_z^2, \quad \text{Eq.8}$$

The combined load and moment equation,
,

$$\frac{Pr}{\alpha rPs} + \frac{Mr}{\alpha mMs} \leq 1, \quad \text{Eq.9}$$

Where,

$\sigma^{buckling}$	=	buckling stress
fy	=	yield stress,
Es	=	elasticity of modulus,
t_w	=	wall thickness,
r_m	=	mean wall radius,
$\sigma^1,\sigma^2,\sigma^3$ section,	=	principle stress acting on the tower
Vb	=	basic wind speed in m/s,
Vz	=	design wind speed at any height z,
P_d	=	design wind pressure,
Pr	=	required level axial force,
Ps	=	maximum strength of tower,
Mr	=	required level moment,
Ms	=	maximum bending strength,
α_r,α_m resisting factor,	=	force and moment
k_1,k_2,k_3,k_4, k_a,k_d,k_c code,	=	factors taken from IS:875
Fs	=	factor of safety,

Material used A36 steel,

Density,	=	7800kg/m3,
Young's modulus of Elasticity,	=	200GPa,
Poisson ratio	=	0.26,
Tower Weight acting On the top portion	=	4551e3N
Weight of the Instrument	=	5Kg

5. RESULT AND COMPARSION

It is clear from figure 01 and 02 that wind speed and design wind load increases when the tower height increases. The maximum wind load acts on the top most portion of the tower which produces maximum bending moment at the bottom portion of the tower. Fig 03 and fig 04 indicates the Von-misses stress analysis and displacement results which indicates the maximum stress occurs at the bottom portion of the tower is 2.76e09 N/m^2. The static structure analysis is done by taking the shell element on ANSYS simulation environment. The boundary conditions are assumed as a cantilever beam and a point load action at the top portion of the tower. Fig 05 indicates the linear buckling result which shows the factor of safety 2.67.The buckling analysis are done on ANSYS by considering the five modes of buckling.

5.1 Wind Pressure and Design Wind speed

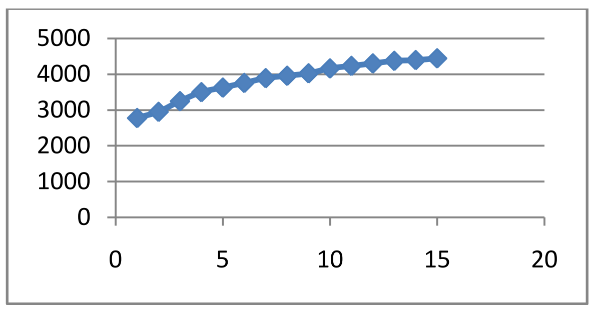

Fig. 01

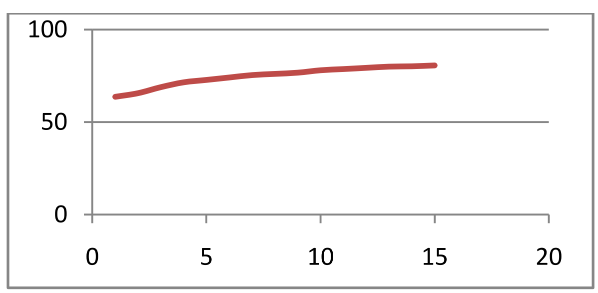

Fig. 02

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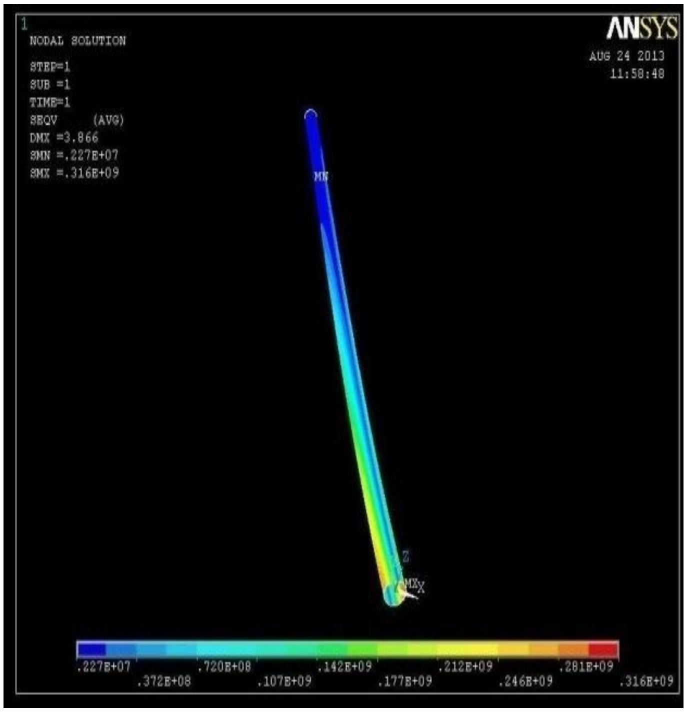
5.2 Static Structure



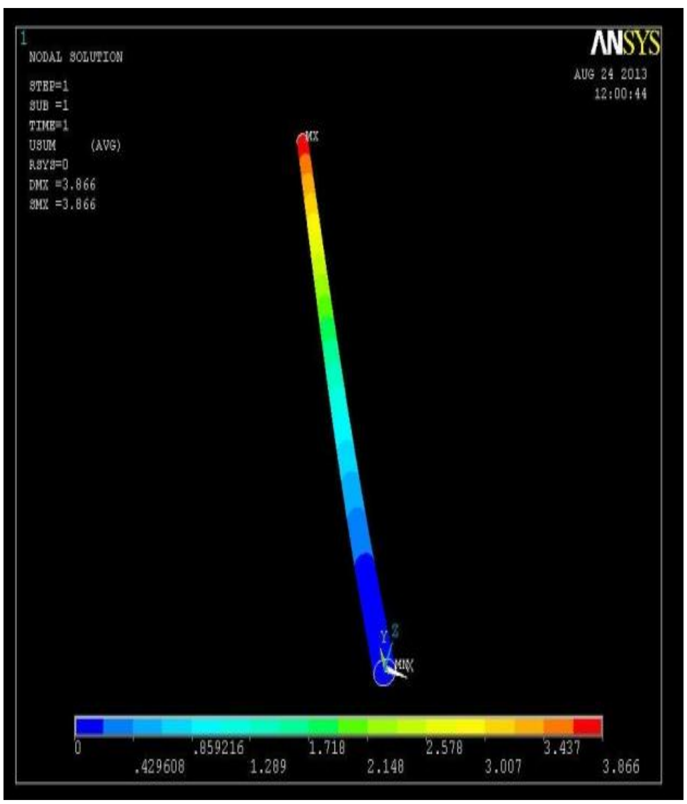


Fig.03. Fig.04

5.3 Linear buckling

***** INDEX OF DATA SETS ON RESULTS FILE *****
SET TIME/FREQ LOAD STEP SUBSTEP CUMULATIVE
1 0.17376E+07 1 1 1
2 0.17428E+07 1 2 2
3 0.17714E+07 1 3 3
4 0.17714E+07 1 4 4

```
***** POST1 NODAL STRESS
LISTING *****
PowerGraphics Is Currently
Enabled
LOAD STEP= 1 SUBSTEP= 1
TIME= 1.0000 LOAD CASE= 0
SHELL NODAL RESULTS ARE AT
TOP/BOTTOM FOR MATERIAL 1
NODE S1 S2 S3 SINT SEQV
1 -0.21812E+07-0.86960E+08-
0.31337E+09 0.31119E+09
0.27865E+09
1 -0.19568E+07-0.77893E+08-
0.28150E+09 0.27954E+09
0.25036E+09
2 0.50032E+07-0.52182E+06-
0.16047E+08 0.21051E+08
0.18904E+08
2 0.64934E+07-0.43391E+06-
0.16470E+08 0.22964E+08
0.20402E+08
3 -0.20820E+07-0.83137E+08-
0.29979E+09 0.29771E+09
0.26659E+09
3 -0.18658E+07-0.74431E+08-
0.26922E+09 0.26736E+09
0.23947E+09
4 -0.17879E+07-0.71862E+08-
0.25981E+09 0.25802E+09
0.23110E+09
4 -0.15955E+07-0.64211E+08-
0.23309E+09 0.23149E+09
0.20740E+09
5 -0.13071E+07-0.53677E+08-
0.19571E+09 0.19440E+09
0.17423E+09
5 -0.11495E+07-0.47689E+08-
0.17507E+09 0.17392E+09
0.15595E+09
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5.4 Vibration

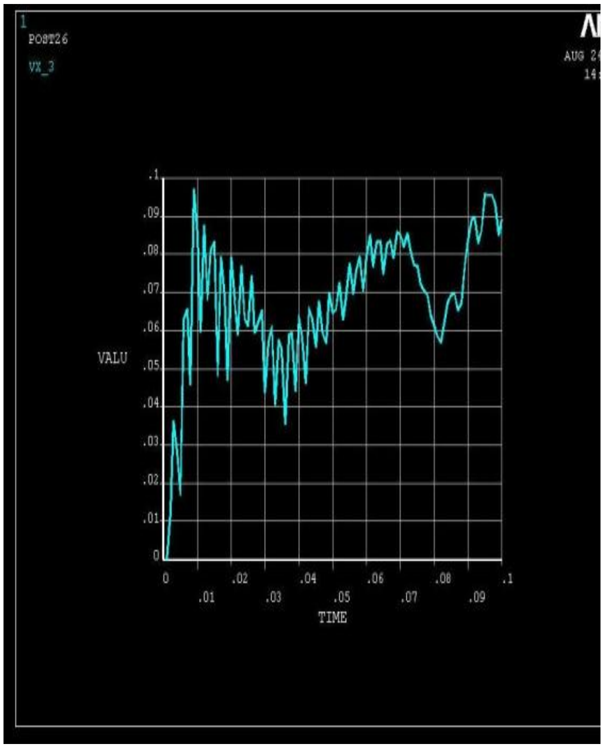

Fig.06

```
***** INDEX OF DATA SETS
ON RESULTS FILE *****
SET TIME/FREQ LOAD STEP
SUBSTEP CUMULATIVE
1 0.28759 1 1 1
2 0.28759 1 2 2
3 1.3700 1 3 3
4 1.3700 1 4 4
5 2.4104 1 5 5
6 2.4104 1 6 6
7 3.1608 1 7 7
8 3.1608 1 8 8
9 3.4791 1 9 9
10 3.4791 1 10 10
```

5.5 Comparison

Table01-Bergar ABAM 100m steel tower characteristics afterLanier2005

Design data	100mTubular steel tower	150 m tubular steel tower (Monitoring)
Volume in m^3	30	59.48
Total weight in KN	2296	45551.311
Base outer dia.in m	5.791	6
Base thickness in m	0.0254	0.035
Top dia. in m	2.896	3.2
Top thickness	0.009525	0.185
Middle dia. in	4.267	4.32
Von misses stress	0.4922 (DCR)	2.76e09 (N/m^2)
Buckling	0.37 (DCR)	2.89 (FOS)
Natural frq. In Hz.	0.4059	0.2859

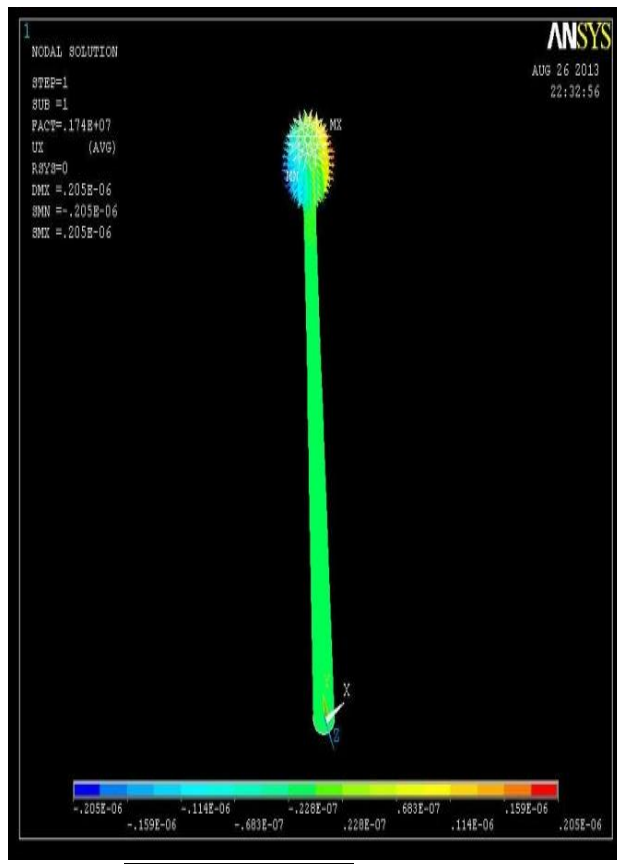

Fig.05

6.0Discussion

It is clear from fig.01 and fig.02 that maximum design wind speed is near about 80m/s and maximum design pressure will be 4500 N/m^2 which would be the design criteria for onshore conditions. Since, the above design is based on the assumption of linear variation of outer dia. and thickness with the interval of 10m height. The effect of Seismic, Earthquake and Tsunami effect on the tower performance is not considered.Fig.03 and Fig.04 indicates the von misses results using ANSYS software and the maximum stress acting on the tower is much below the modulus of elasticity.Fig.05 indicates the linear Buckling result which shows the factor of buckling is near about 2.89 (Out of five modes of buckling).Fig.09 indicates the velocity diagram with respect to time assuming the range of frequency 0 to 100 Hz. Due to the unavailability of data related to load frequency, the fatigue analysis is not being carried out, while the natural frequency of vibration for the tower is calculated to be 0.2589 Hz.

7.0Conclusion and Future Scope

Ultimately, this paper provides the overall design of onshore tubular steel tower at Paradip port situated at the confluence of river Mahanadi and Bay of Bengal. Due to limitation of transportation it is difficult to manufacture steel plates more than 4.3 m. So, research is needed to improve the manufacturing technology in steel sectors and design of towers in such a way, so that the better utilization of steel could be done which is the current major issue in front of researchers and scientists. Research is also needed to incorporate the use of hybrid towers instead of steel for the tower height exceeding 100m. Tower dimensions were determined by the combination of strength and fatigue. As such, the tower's operational design life is approximately 35 years. In operating conditions, the steel tower design causes very large deflections which produce maximum tower drift of 1.65%. In this case, the base diameter of the tower would need to be increased to decrease the deflections, which would finally restrict the length of the sections of the towers for transportation. It is also concluded that, more research is required in the field of tower design above 100 m height.

ACKNOWLEDGMENT

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